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EXPERIMENTAL ANALYSIS OF COMBUSTION CONTROL STRATEGY OF HOMOGENEOUS CHARGE COMPRESION IGNITION ENGINE

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Abstract--Homogenous charge Combustion ignition (HCCI) engines are being considered as an alternative to diesel engines. The HCCI concept involves premixing fuel and air prior to induction in to the cylinder (as is done in current spark- ignition engine) then igniting the fuel –air mixture through the compression process (as is done in current diesel engines). The combustion occurring in HCCI engine is fundamentally different from a spark ignition and Diesel engines in that of heat release occurs as a global auto ignition process, as opposed to the turbulent flame propagation or mixing controlled combustion used in current engines . The advantage of this global auto ignition is that the temperature within the cylinder are uniformly low, yielding very low emission of oxides of Nitrogen(NOx, the chief precursors to photochemical smog). The inherent feature of HCCI combustion allows for design of engines with efficiency comparable to, or potentially higher than, diesel engines.

This paper describes the results & Strategy proposed to control the combustion of HCCI engine. This is achieved by controlling air path & fuel path to maintain start of Combustion. An experimental results of Combustion Control analysis are presented to prove the strategy used for these experiments.

Key words- SOI, BGR, EGR, Turbocharger, SOC

I. INTRODUCTION

In HCCI, A Homogenous mixture of air and fuel is compressed and ignited by the heat of compression HCCI combustion can be considered as a hybrid form between the Diesel and Otto combustion processes as it combines the homogenous mixture preparation of an Otto engine with the compression ignition of diesel engine. However, the combustion process is different. When heat and pressure of the mixture are high enough, the compressed homogenous charge ignites simultaneously at multiple spots in the combustion chamber, so there is neither a diffusion flame (as in a Diesel engine) nor a flame front traveling through a premixed charge, as in a spark ignition engine. Furthermore, the air-fuel mixture is often diluted with combustion products (i.e.), in order to limit the rate of combustion or to delay the start of ignition. The HCCI combustion process has been known for a long time but except for some odd application, it has not been used for production engines. In the field of internal combustion engine research, however, it has gained considerable interest in the last decade, mainly because of the large reduction in NOx emissions it offers. Since the mixture is lean, diluted and homogenous, theoretically there is none of high temperature stoichiometric combustion zones that are essential for necessary for NOx formation and no fuel rich soot-forming zones. Whether these NOx and soot-forming zones are really absent depends on the actual homogeneity of the air fuel mixture. Numerous experiments have shown that the NOx and soot emissions are indeed drastically reduced and in some cases approach zero

II. RESEARCH METHODOLOGY-

The several phases of the combustion can be described according to the timeline detailed in Figure 1. There are two main phases corresponding to the air path subsystem (which involves the intake manifold, the intake throttle, the turbocharger, and the EGR valve) and the fuel path subsystem (which consists of the injectors). The HCCI combustion mode is highly sensitive to the thermodynamic conditions at the intake. Accurate air path control and adaption of the fuel path are thus required to manage the HCCI combustion. Air path controllers have long been proposed. They result in efficient tracking of the intake manifold variables (reference total mass, burned gases rate (BGR), and temperature of the intake charge) even during transients. Usually, three main actuators are employed (EGR valve, intake throttle and Turbocharger). During the cylinder compression phase, fuel is injected and mixed to be considered. Our focus is on developing an improved method capable of achieving the desired transients. To address the discussed issues, i.e. to circumvent changes in the cylinder initial conditions, we propose to use the start of injection (*soi*) as an actuator to control the start of combustion during BGR (Burned Gas Rate), pressure and temperature transients. This is the main contribution of this paper. A noticeable point of our approach is that this control variable can be used on all commercial line engines without requiring any hardware upgrade. Controlling the start of combustion (*soc*) is an efficient strategy in the presented context of HCCI engines. Indeed, instead of a classic flame propagation phenomenon, spatially distributed starts of combustion are simultaneously observed in the chamber. the compressed air and burned gas mixture. The fuel vaporizes and auto-ignites after the so-called ignition delay . Standard fuel path control strategies focus on controlling injected fuel mass. Eventually, a smoke limiter can be added on, providing a fuel mass limiter based on a fuel/air ratio limitation to avoid smoke emissions during transients. This is usually sufficient to produce the torque requested by the driver. As we will now discuss it, these controllers are often not sufficient to maintain a stable Diesel HCCI combustion. In fact, and by contrast to conventional Diesel combustion mode, slight offsets of cylinder initial conditions (e.g. pressure, temperature, or composition) easily cause problems. In practice, if the fuel path controller is not coordinated to the air path controller, combustion stability is jeopardized during transients.

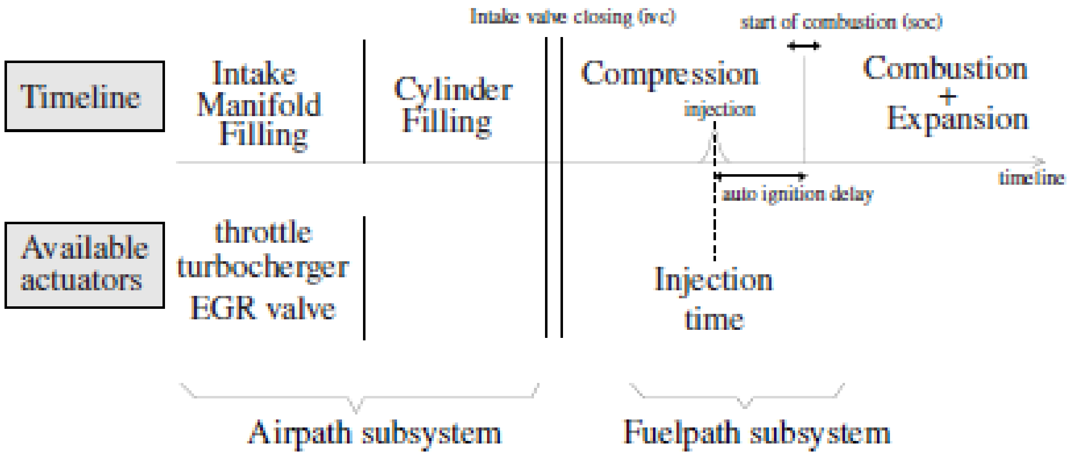
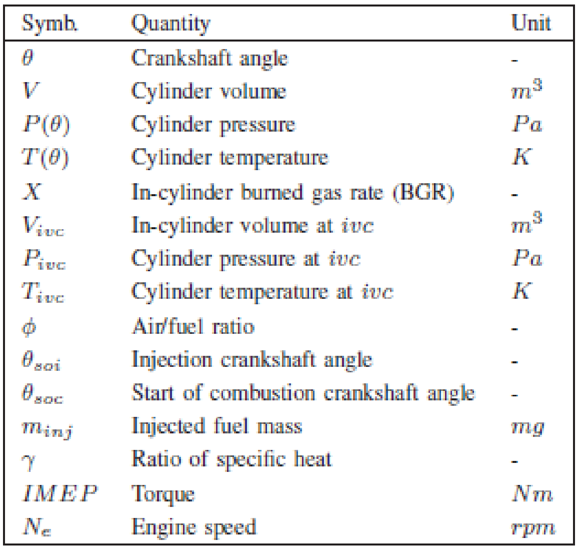


Figure 1: Timeline of Diesel engine cycle with direct injection

A complete nomenclature of engine variables is given in Table 1. In generally observed engine setups, air path and fuelpath controllers are used to guarantee that engine variables (pressures, temperatures, and injected fuel mass among others) . These controllers are used in the context of actual vehicle implementation which imply frequent transients due to varying driver torque demands

(Pm) and engine speed (N). In turn, these demands result in frequent transients for reference air path and fuel path variables



Symb.	Quantity	Unit
θ	Crankshaft angle	-
V	Cylinder volume	m^3
$P(\theta)$	Cylinder pressure	Pa
$T(\theta)$	Cylinder temperature	K
X	In-cylinder burned gas rate (BGR)	-
V_{ivc}	In-cylinder volume at ivc	m^3
P_{ivc}	Cylinder pressure at ivc	Pa
T_{ivc}	Cylinder temperature at ivc	K
ϕ	Air/fuel ratio	-
θ_{soi}	Injection crankshaft angle	-
θ_{soc}	Start of combustion crankshaft angle	-
m_{inj}	Injected fuel mass	mg
γ	Ratio of specific heat	-
$IMEP$	Torque	Nm
N_e	Engine speed	rpm

Nomenclature of Engine

III . EXPERIMENTAL SETUP-

All experimental results presented in the following have been obtained on a four cylinder direct injection Kirloskar Diesel engine running in HCCI combustion mode. Exact specifications are reported in Table 1. A high pressure EGR circuit is used. It extracts hot burned gases upstream of the turbine and introduces them downstream of the compressor. A valve allows the EGR rate to be controlled. Finally, both the air and the EGR circuits include an air cooler to keep the intake manifold temperature around 300K.

Table No 1

Engine Type	Kirlosker Oil Engine
Bore	81 mm
No of Cylinder	04
Stroke	92.3 mm
Displacement	80 CC
Piston type	Toroidal bowl
Compression Ratio	17

Table No 2 - Injection system Specification

Injection System	Bosch Common Rail
Injector type	Valve covered orifice
No. Of nozzle orifices	10
Nozzle Orifice diameter	0.11 mm
Included angle	60 deg

Table No 3 - Emission and Fuel Consumption Measuring equipment

Fuel Flow Meter	Burette type
Smoke meter	SLP670, Ecophy make
HC,CO & PM meter	Neptune make
Nox meter	CLD70IELT , Ecophy make

The general control scheme is presented in Figure 2. In this setup, the injection crankshaft angle i is not simply set to its reference value but is corrected according to the air path errors .The model is used in the controller design. This model has been calibrated on 50 points of the whole engine operating range using classical optimization method. The controller has been integrated in the complete IFP engine control system already developed in MATLAB Software. RTW (Real Time Workshop) and XPC target toolboxes are used for real time code generation

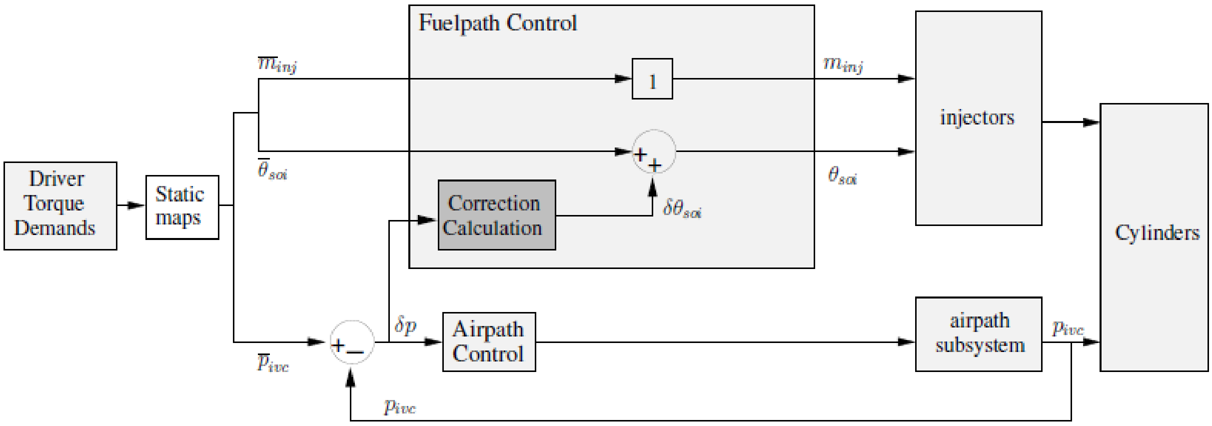


Figure 2- System designed to control combustion timing of HCCI engine.

III. EXPERIMENTAL RESULTS-

The air path control regulates the intake manifold pressure and BGR around their reference values in order to meet torque demands as shown in Figure N0 3and 4 . Instantaneous tracking of these reference values make the new fuel path controller correct the injection crankshaft angle reference value Shown in figure No 04. The injection crankshaft angle sent to the injectors is then different from its reference value. This is caused by slight influences of the proposed fuel path controller on the exhaust conditions (mainly pressure and temperature) which have an impact on the intake conditions via the EGR . During increasing torque transients, intake manifold pressure is lower than its reference and BGR is higher than its reference, both errors leading to a longer auto ignition time than the reference. Without injection crankshaft angle correction, the soc (start of Combustion) occurs too late which makes the combustion very close to the instability. With the new fuel path controller, the injection occurs sooner as in figure No 4. The start of combustion and combustion are then closer to their reference, (during decreasing torque transients). Secondly, torque response during transients is much faster with the proposed upgraded control module. The engine noise transients have been improved too. With the classical fuel path strategy, noise level varies a lot during torque demand transitions.

On the other hand, with the proposed correction strategy, noise transients happen faster and over and undershoots are much smaller or even disappear .The proposed strategy stabilizes much quicker the combustion timing. Combustion, even during transients, seems then to be much closer to the reference one (at least timing is). This clearly proves that the strategy proposed in this paper can control the combustion timing up to its mark.

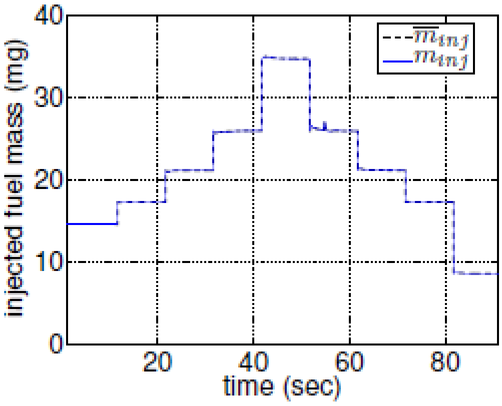


Fig 3- Results of Fuel Mass V/S Time

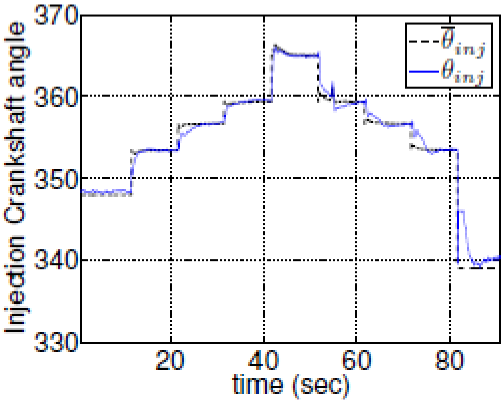


Fig 4- Results of ICA v/s Time

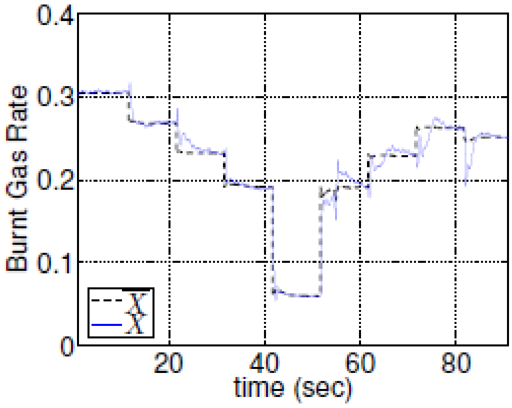


Fig 5- BGR V/S Time

IV. CONCLUSION-

An improvement for the fuel path control strategy of HCCI diesel engine has been presented. Instead of directly setting the injection crankshaft angle to its reference value, we propose to synchronize the fuel path to the airpath. This controller is mainly based on the linearization of an auto ignition delay model. This method can be applied to engine with external or internal Gas recirculation, to naturally aspirated engine, throttled engines and/or with turbochargers. The presented experimental results stress the relevance of this new approach. Stall problems during transients are solved and combustion stability is improved. At the light of these results, controlling the start of combustion *seems* to be an appropriate solution to improve the stability of the HCCI combustion

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